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RIGHT-LATERAL DISPLACEMENT OF PLEISTOCENE SEDIMENTARY DEPOSITS ALONG THE SAN ANDREAS FAULT, PALMDALE TO CAJON PASS, SOUTHERN CALIFORNIA.

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ABSTRACT

The Harold Formation (Noble, 1953), of apparent middle Pleistocene age, consists of perched, minimally deformed alluvial, colluvial, and lacustrine deposits in the south Palmdale area. The formation was deposited in a shallow, elongate basin of 10-15 km^2 developed along the northwest-striking San Andreas fault rift. Clastic constituents were derived mostly from mountainous terrain 5 to 10 km to the west, on the southwest side of the rift. Source rocks were mainly Pelona Schist, gneissic-granitic rocks, and syenite; minor but distinctive angular to subrounded clasts of white marble were derived from inclusions of plutonic rocks displaced upward along the inner San Andreas zone in the depositional area.

My detailed mapping (1991-1998; scale 1:9,600) discloses that marble-clast bearing deposits of the Pelona Schist-clast member of the Harold Formation are right-laterally displaced ~2.5 km along the San Andreas fault. Previous estimates of displacement of deposits identified as Harold Formation range from 8 to 16 km. My work also shows that deposits of the Harold Formation at Palmdale are unique and not correlative with miscellaneous Pleistocene deposits previously identified as Harold Formation extending discontinuously southeast to Cajon Pass.

Mapping from Palmdale southeast nearly to Big Pines discloses that additional middle to upper Pleistocene deposits are right-laterally displaced along the San Andreas: These include Shoemaker Gravel (middle Pleistocene), ≤ 5 km; very old alluvium of Brainard Canyon (middle [?] Pleistocene), 3-5 km; very coarse older alluvium of Big Rock Creek (middle Pleistocene), 3-6 km; and a facies contact within older alluvial fan deposits (middle [?] Pleistocene) directed NE from Pinyon Ridge, 2.3 km (offset).

My mapping consistently shows that deposits ranging in age from late Pliocene to late Pleistocene have been displaced along the Mojave segment of the San Andreas at a rate of ~0.5 to 1.0 cm/yr; the consensus rate is ~3.0 to 3.5 cm/yr.

FIGURES

INTRODUCTION

Total right-lateral displacement on the San Andreas fault in central and northern California is almost wholly interpreted to be ~325 km (James et al, 1993; Powell, 1993; Sims, 1993). Displacement along the faults of the complex San Andreas system in southern California is also perceived to be ~325 km (Crowell, 1982; Crowell, J.C., 1996, personal communication; Powell et al, eds., 1993; Powell, 1993). Of the southern California total, ~170 km displacement is commonly interpreted to have occurred along the Mojave *segment* of the San Andreas fault [*sensu stricto*]) (Matti and Morton, 1993; Powell, 1993; Weldon et al, 1993)(Figure 1). This segment is perceived to have developed between 5 and 4 Ma (Crowell, 1982; Powell, 1993; Matti and Morton, 1993).

FIGURE 1

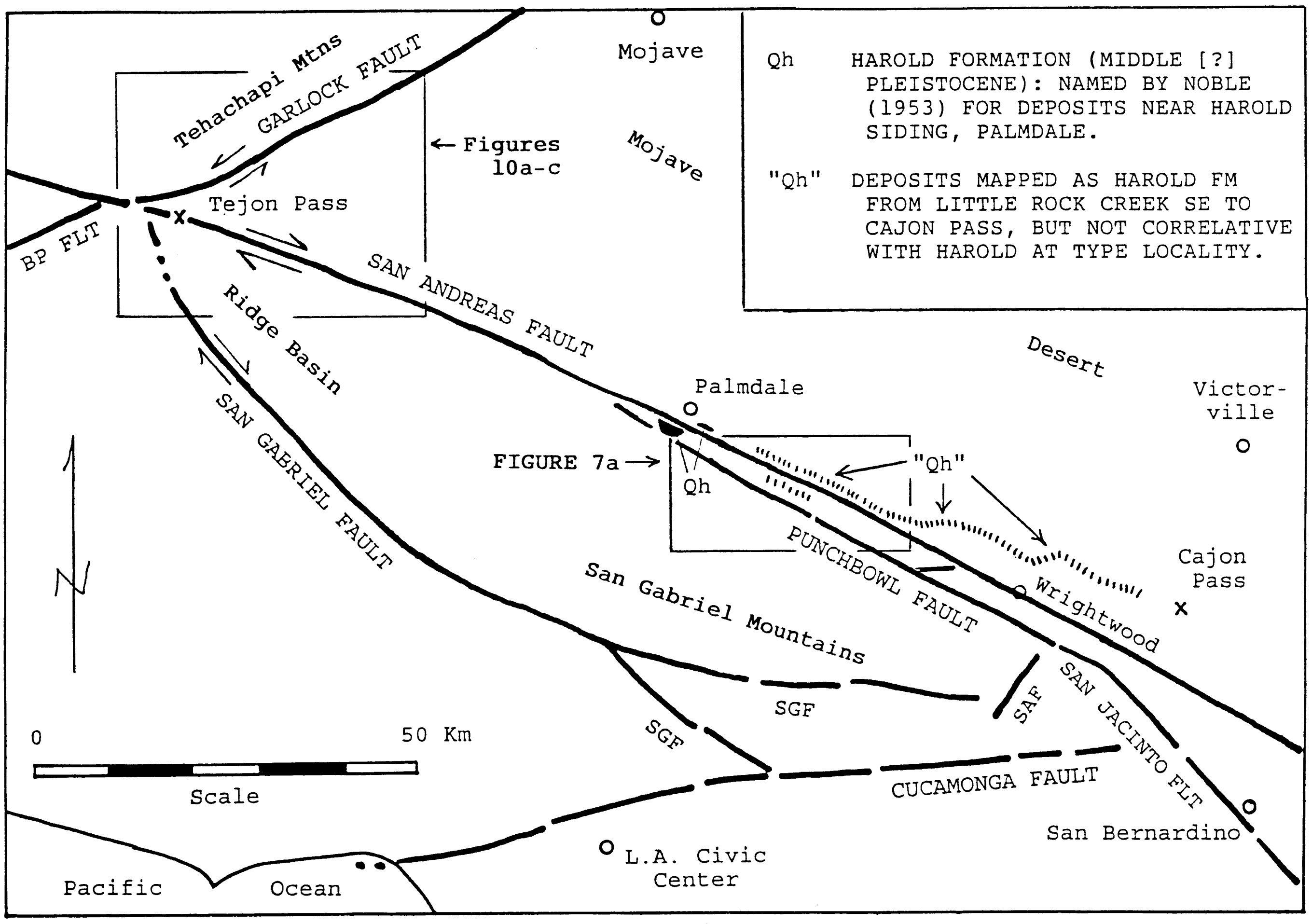

FIGURE 1. Simplified fault map of a part of southern California showing study area and selected geologic units: Qh, Harold Formation (Noble, 1953) (middle [?] Pleistocene); "Qh", deposits southeast of Palmdale previously misinterpreted as Harold Formation. SYMBOLS: SAF, San Antonio fault; BP FLT, Big Pine fault. (Note: The San Andreas fault between Tejon Pass and Cajon Pass commonly is referred to as the Mojave Desert strand, or segment.)

These findings have led to a near consensus of the geologic community that the average displacement rate for the Mojave segment since its birth is ~3.5 cm/yr (Brown, 1990, p. 107; Weldon et al, 1993, p. 161-162, 165). Petersen et al (1996, p. A-1) assign a late Pleistocene-Holocene slip rate of 30 mm/yr to the Mojave segment and a rate of 34 mm/yr to the Cholame segment to the northwest. Barrows et al (1985) mapped in detail the central 100-km segment of the Mojave segment: They interpret (1985, p. x, 128) that right-lateral displacement along the segment since 4.5-5.0 Ma is ~102 km (an implied displacement rate of ~2.0-2.5 cm/yr).

The findings of a few geologists are starkly in contrast to those of the consensus. Woodburne (1975, p. 1-2) states: "None of the

> branches of the San Andreas fault appears to have undergone more than about 20 to 30 km of right-lateral slip during or after Hemphillian time, or during the past 10 m.y. or less. Even including 24 km of right-lateral slip on the San Jacinto fault zone, the aggregate slip on the San Andreas fault system during this time appears to be on the order of only 60 km, substantially less than required to compensate for the 250 km involved in the opening of the Gulf of California during the past 5 m.y."

Robert H. Paschall (personal communication, 1994-1998) argues that lateral shortening dominates in the Transverse Ranges, in which the Big Bend Segment of the San Andreas fault lies, with consequent diminution of strike-slip displacement. The lateral shortening is a product of north-south forces portrayed by Hill and Dibblee (1953, Fig. 6, p. 456) and revealed more specifically by Crowell (1968, Fig. 1, p. 325).

My detailed geologic mapping at critical places along the San Andreas fault between Tejon Pass and Cajon Pass shows that nonmarine sedimentary deposits within the age range of ~0.5 to 2 or 3 Ma, including the Harold Formation, have been right-laterally displaced ~0.5 to ≤ 1.0 cm/yr since their deposition (Weber, 1996, 1998a-b).

The findings herein are based on detailed geologic mapping along the San Andreas fault in the following areas: Palmdale southeast to Jackson Lake, including Juniper Hills (Weber, 1996; 1998b, unpublished; scales, 1:12,000 to 1:9,600); Lake of the Woods southeast to Quail Lake, and northern Ridge basin (Weber, 1988, 1998a; 1:24,000 to 1:6,000); and Cajon Pass (upublished, 1:12,000).

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The following age classification is used for the Pleistocene (Roy J. Shlemon, personal communication, 1985): early Pleistocene, 1.8 to 0.73 Ma; middle Pleistocene, 0.73 to 0.125 Ma; late Pleistocene, 0.125 Ma to 10 or 11 Ka; latest Pleistocene, 15 or 20 to 10 or 11 Ka. Berggren et al (1995, Figure 4) provide a similar, more generalized classification.

DESCRIPTION OF HAROLD FORMATION

Lithology

The Harold Formation was named by Levi F. Noble (1953) for minimally deformed alluvial, colluvial, and lacustrine deposits in the south Palmdale area, 60 km north of Los Angeles civic center (Figure 1). The type locality (Noble, 1953, Explanation for Map Units) is in the "--hills half a mile southwest of San Andreas fault and a mile southeast of Harold Siding on Southern Pacific Railroad." (The site of Harold siding is shown herein on Figures 2a-b.) The name "Harold Formation" also has been utilized by Noble (1954b) and by subsequent workers to identify certain additional nonmarine deposits of early to middle Pleistocene age extending discontinuously along the San Andreas fault from Palmdale southeast to Cajon Pass, a distance of 80 km (Figure 1).

Barrows et al (1985) partly mapped the Harold Formation as "undifferentiated" and partly divided it into four members, including three principal members locally at Palmdale: Pelona Schist-clast member, granitic arkose member, and lake deposit member. In all, Barrows et al (1985) mapped as Harold Formation deposits extending discontinuously for 45 km along the San Andreas fault, from western Anaverde Valley southeast to Mile High. They used the name Harold Formation to identify a variety of deposits: Most of these lie stratigraphically between highly deformed upper Tertiary sedimentary rocks and younger perched alluvium (including Nadeau Gravel).

Deposits of the Harold Formation at Palmdale mostly range from horizontal to moderately inclined (20-25°); they apparently dip more steeply only where in direct contact with active faults of the San Andreas zone. For the greater part they lie horizontally on an erosional surface developed on highly deformed rocks of pre-Quaternary age (Figure 3). The deposits range in thickness from < 5 to ~30 m, averaging ~10 m. The maximum dimension of clasts in the coarsest deposits is ~35 cm.

Exposures of the Pelona Schist-clast member of the formation can be observed easily at two places: (1) Southwest of the San

Andreas fault, horizontal to gently north-dipping deposits are exposed in cuts for Pearblossom Highway 50 to 200 m south of the California Aqueduct (Figure 2a, locality 1). Clasts of Pelona Schist and gneissic-granitic rocks are common here; those of syenite are sparse. In a low cut on the west side of the highway, 800 m south of the aqueduct, deposits can be observed to overlie an essentially horizontal erosion surface developed on moderately to steeply dipping Tertiary conglomerate. (2) Northeast of the San Andreas, horizontal to gently north-dipping deposits of the Pelona Schist-clast member are exposed in a west-facing cut for 40th Street East, 50 to 100 m north of Barrel Springs Road (Figure 2a, locality 2; Figure 4). Clasts of Pelona Schist and syenite are common in gently north-dipping beds exposed here; distinctive angular to subrounded clasts of marble are also common in a few strata.

Provenance (Pelona-Schist clast member)

The Pelona Schist-clast member constitutes a distinctive variety of older (perched) alluvium. Alluvium in the Palmdale region is largely transported northeastward from the San Gabriel Mountains across the San Andreas fault into the Mojave Desert. It is deposited directly or diagonally across the fault into the desert at some places, and along the fault's rift for as much as 5 to 13 km, then into the desert, at other places. Locally, sediments are transported diagonally across the fault within Little Rock Creek canyon and Hunt Canyon; sediments are carried southeastward along the fault and then into the desert within Amargosa and Anaverde creeks, northwest of Palmdale (Figure 5). I interpret that sediments have been transported into the desert from Little Rock Creek canyon since at least early Pleistocene time.

Transport and deposition of alluvial sediments relate to cycles involving tectonic and climatic events. Mantles of alluvium formed during wet cycles are dissected, uplifted, and eroded into isolated patches; the deposits eventually are eroded completely away. Only sediments deposited into deeper troughs developed along the San Andreas fault zone have survived to become part of the long-term geologic record (e.g., Punchbowl Formation [12-6 Ma: Woodburne and Golz, 1972; Woodburne, 1975]).

Sediments composing the Pelona Schist-clast member of the Harold Formation were derived from mountainous terrain northwest of Soledad Pass that includes Pelona Schist, granitic-gneissic rocks, and syenite (Figure 6). The sediments were transported in middle Pleistocene time 1 to 8 km southeastward and eastward into a very shallow, elongate basin existing along the San Andreas fault zone (Figure 6). The basin extended southward to within ~2 km of Soledad Pass but apparently did not breach it.

FIGURE 2a

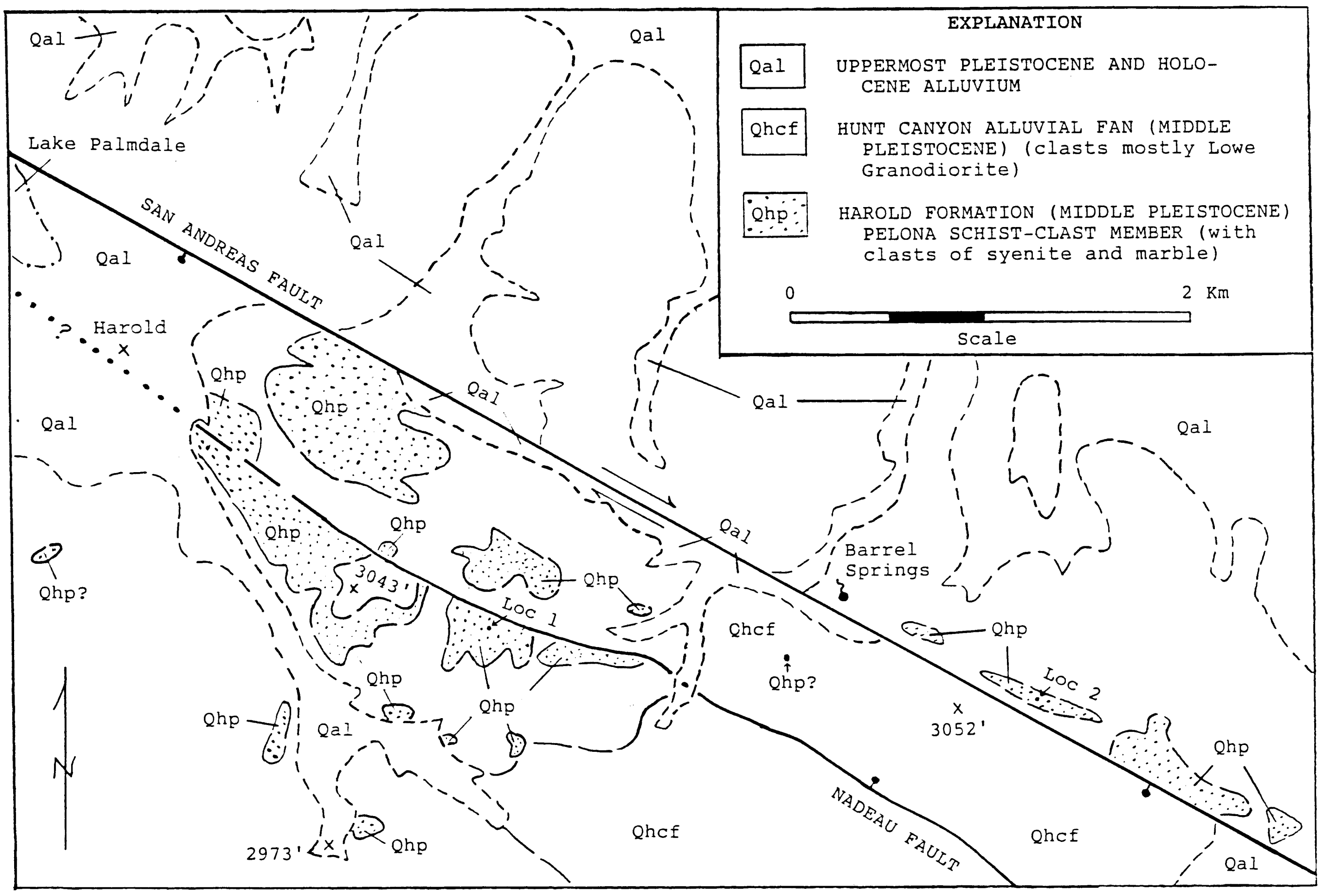

FIGURE 2a. Simplified geologic map of the southeast Palmdale area. The distinctive white marble-clast-bearing Pelona Schist-clast member of the Harold Formation (Qhp) is right-laterally displaced ~2.5 km along the San Andreas fault (Figure 2b). Dark, ball-shaped symbols represent south-facing scarps. Compiled from Weber (1998b). Elevation points are from the Palmdale 7.5 quadrangle published by the U.S. Geological Survey.

FIGURE 2b

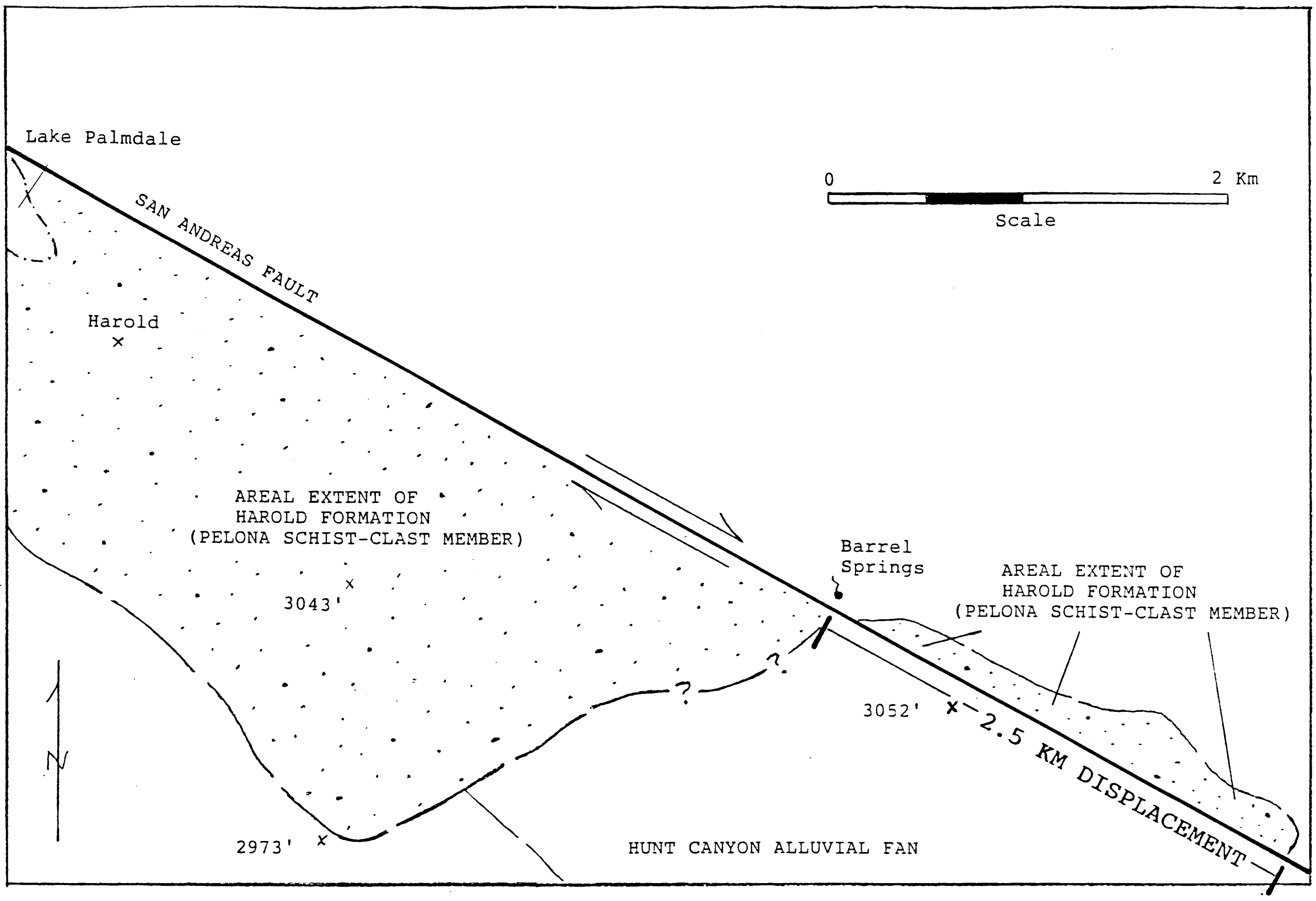

FIGURE 2b. Simplified map adapted from Figure 2a showing ~2.5 km displacement of Harold Formation along San Andreas fault (also see Figure 6).

FIGURE 3

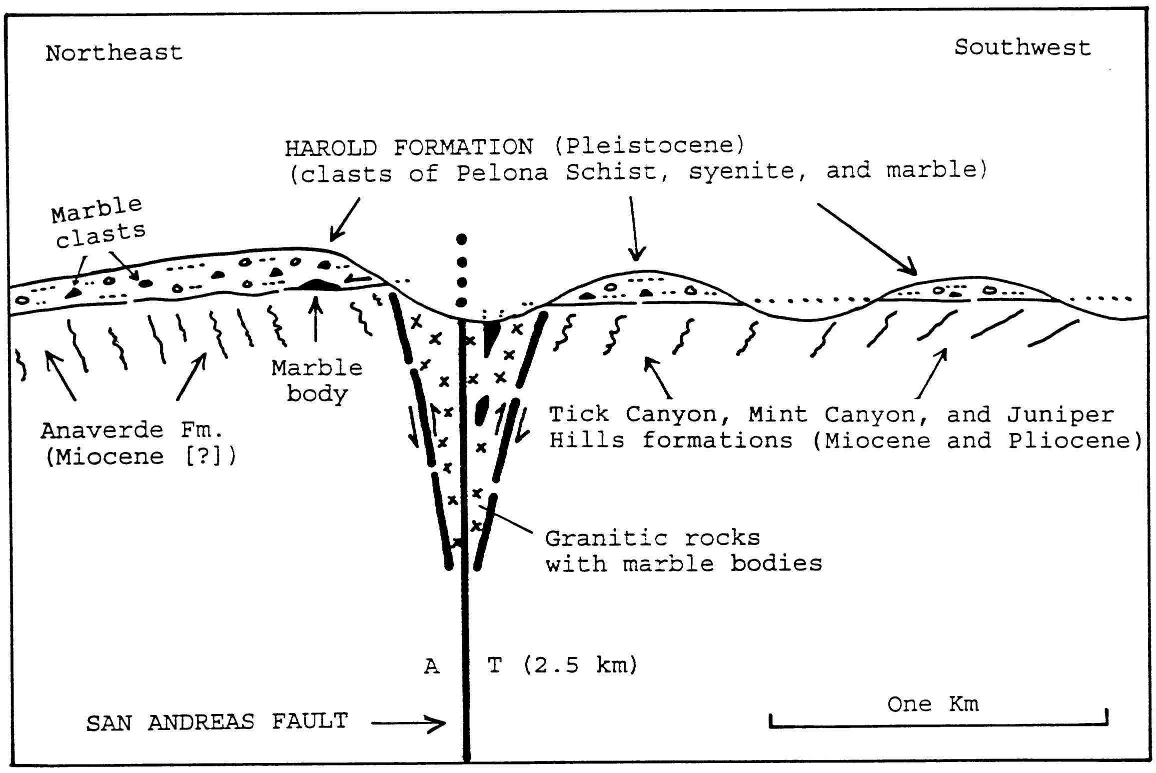

FIGURE 3. Pictorial, idealized cross section across the San Andreas fault, Palmdale area, showing relative position of the Harold Formation. Angular to subrounded clasts of marble were derived locally from inclusions in granitic rocks squeezed upward within the fault zone. The small body of marble overlying the erosional surface underlain by steeply dipping Anaverde Formation (Figure 4) was emplaced northeastward across the fault along with sediments of the Harold Formation.

FIGURE 4

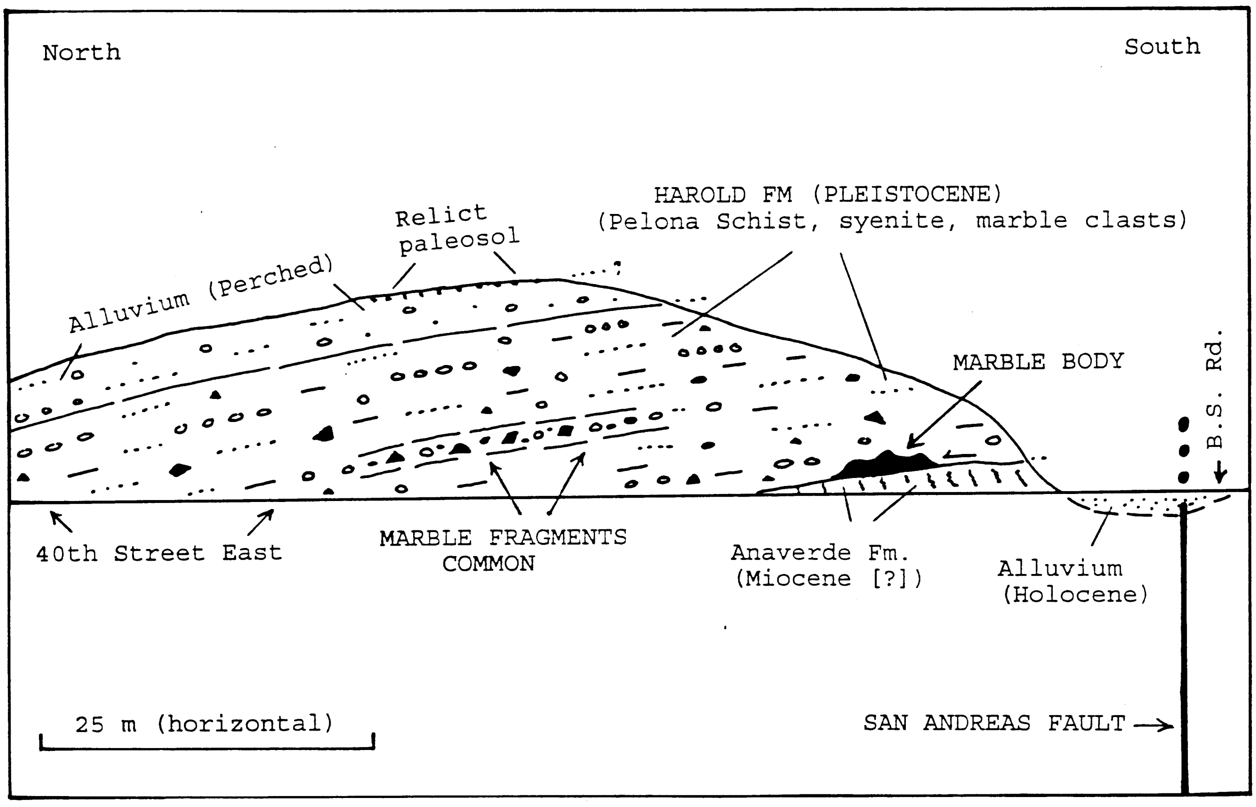

FIGURE 4. Diagram of a roadcut along 40th Street East that exposes gently north-dipping deposits of the Pelona Schist-clast member of the Harold Formation containing angular to subrounded clasts of mostly white marble. The Harold deposits are partly overlain by older (perched) alluvium with a different clast composition. A relict paleosol exposed at the top of the cut has been partially eroded away.

Harold sediments coalesced southeastward with the north-directed Hunt Canyon alluvial fan (derived mostly from the Lowe Granodiorite complex). Thin lacustrine beds of the Harold Formation are interlayered with finer-grained deposits of the fan, as exposed in hillocks 1 km south-southeast of the intersection of Pearblossom Highway and Barrel Springs Road (center N½ NW¼ NW¼ sec. 18, T5N, R11W, SBM) (Figure 6, locality 1). Largely angular to subangular clasts of white marble in the Harold deposits were derived from inclusions in granitic rocks "squeezed up" locally within the inner San Andreas zone and transported < 1 km (Figures 3,4).

Age

The age of the Harold Formation at its type locality and vicinity, as defined by Noble (1953), and as further refined by Noble (1954a,b), Woodburne (1975), Foster (1980, 1982), and Barrows et al (1985), is only approximately known. Noble (1953), mainly on the basis of vertebrate fossils identified by C.L. Gazin, states that the formation is "Certainly Pleistocene and probably upper Pleistocene." The formation is interpreted by Woodburne (1975, Figure 2) to be Rancholabrean ($\leq$ 0.5 Ma).

Ponti and Burke (1980) state that the Harold Formation underlies their "oldest Q1 deposits." Ponti et al (1981; scale 1:62,500) include the Harold Formation and closely associated older deposits of the Hunt Canyon fan within their Q1-3 units, having an estimated age range of 0.13 to 0.45 Ma. Foster (1982, p. 70) states: "The Harold Formation is tentatively assigned an age of Late Irvingtonian 1.2 m.y. - 500,000 years old by [Charles] Repenning (personal communication, 1981) on the basis of fossil pack rats collected from Barrel Springs near Palmdale, California." Barrows et al (1985, p. 114) estimate that deposits they identify as Harold Formation are "Pleistocene, 1.2 to 0.5 m.y."

Based on my observations, the following factors are significant to the relative age of the Harold Formation (Qh).

(a) Qh is more consolidated than most other perched alluvium locally but is not lithified.

(b) Qh is mostly horizontal; it dips greater than ~20-25° only near active faults of the San Andreas zone.

(c) Where exposed in the cut on 40th Street East, Qh is partly overlain by deposits of a different clast composition (Vasquez volcanics common, no marble; Figure 4, perched alluvium). A perched, relict paleosol developed here on Qh is partially eroded away.

(d) Qh overlies breccia-conglomerate with a similar clast lithology 0.8 km west of the intersection of Pearblossom Highway and 25th Street East. Whereas Qh is consolidated but not lithified, strata of the breccia-conglomerate are well lithified

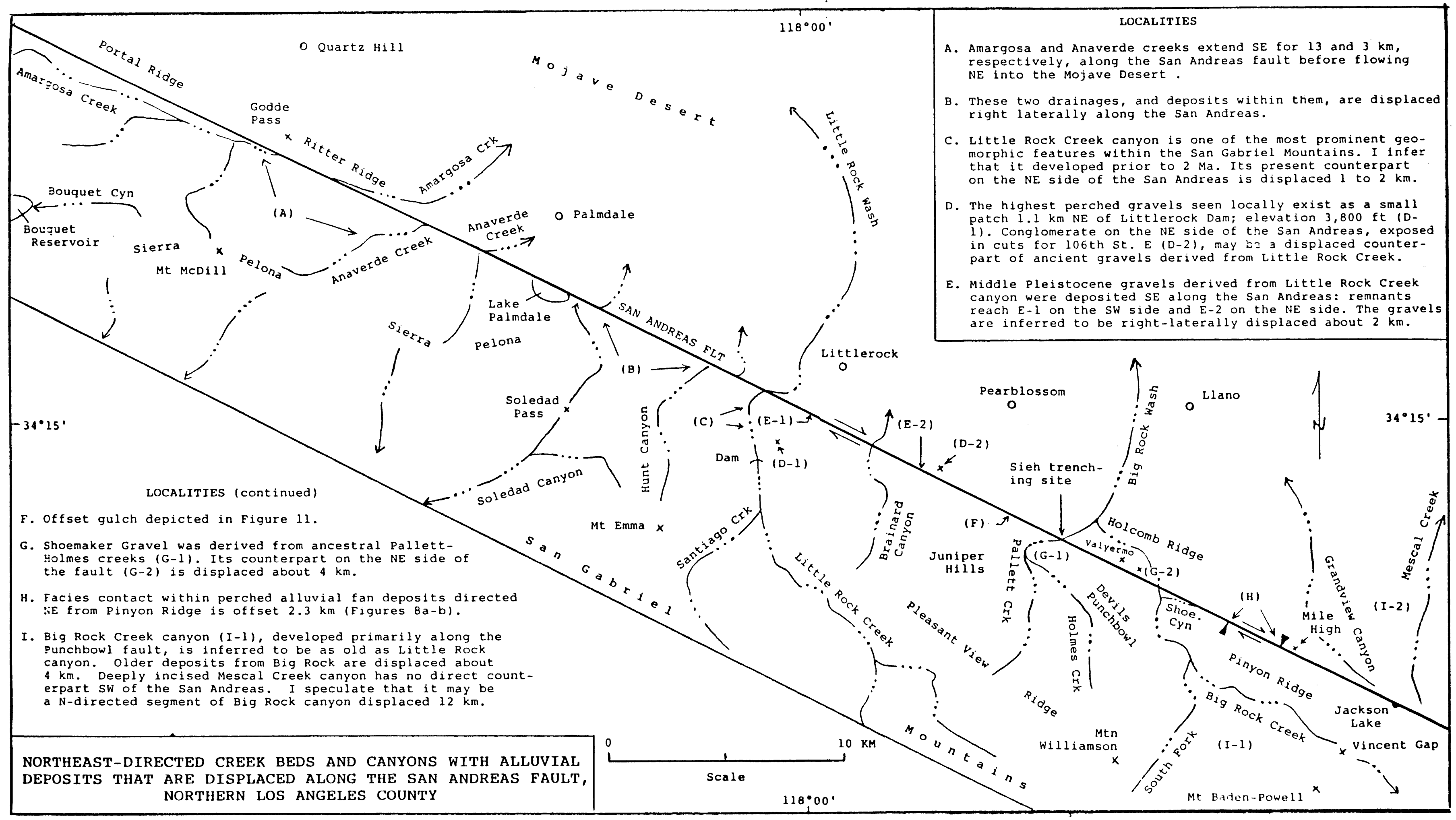

FIGURE 5. Regional map showing principal creek beds extending northeast across the San Andreas fault into the Mojave Desert. Amaragosa and Anaverde creeks extend southeast along the San Andreas rift 13 and 3 km, respectively, before extending north into the desert. Older deposits derived from Little Rock Creek were transported southeast along the fault before carried into the desert. Failure to recognize this phenomenon in some past studies has led to an exaggeration in lateral displacement of remnants of such deposits (E-1, E-2).

FIGURE 6

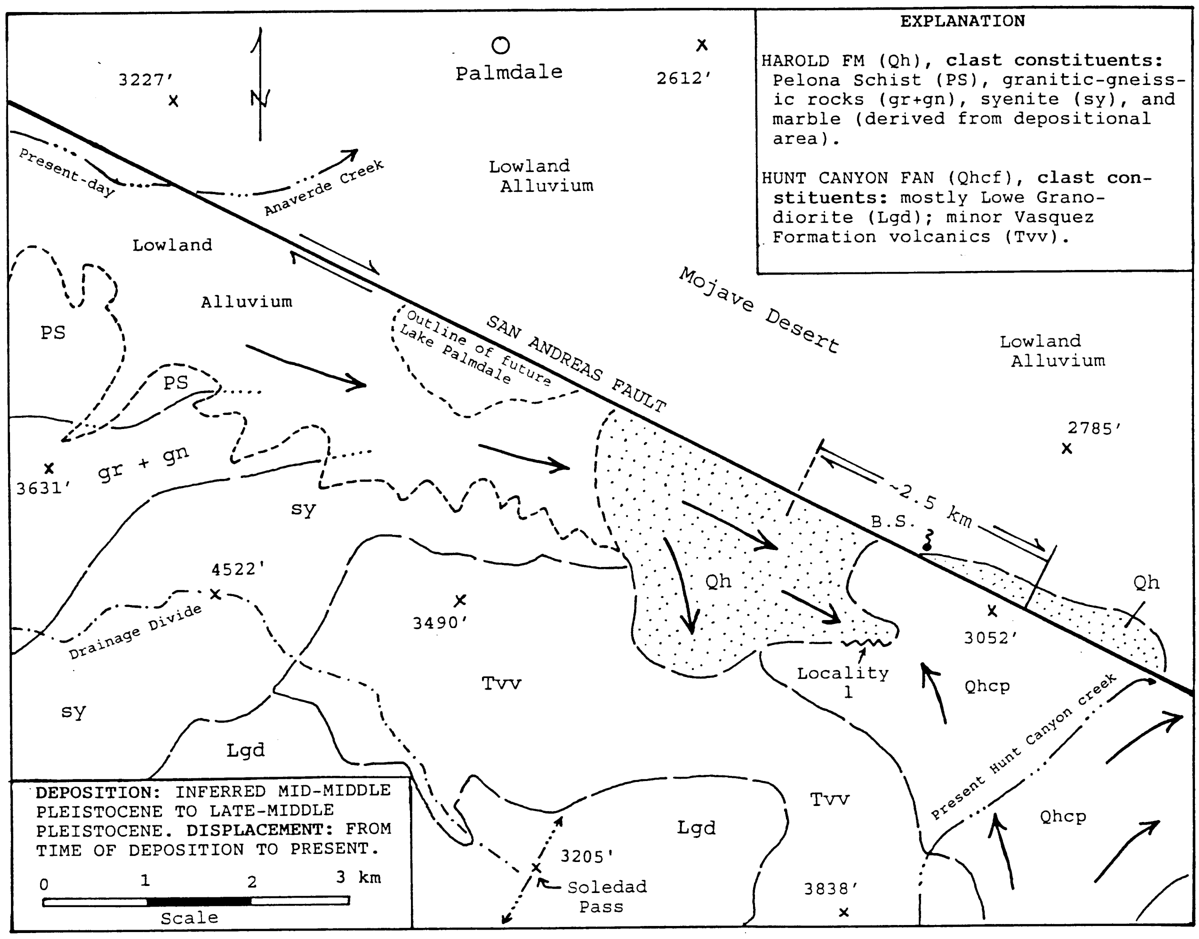

FIGURE 6. Simplified geologic map of the Palmdale region showing direction of transport of sediments of Harold Formation (Qh) and Hunt Canyon alluvial fan (Qhcp). Deposition of thin lake beds of the Harold and fine-grained sediments of the fan coalesced at Locality 1. Displacement of Qh since deposition is ~2.5 km (Figure 2b).

and commonly very steeply dipping to vertical. The latter rocks were mapped as Qh by Noble (1953) and Barrows et al (1985, Plate 1F); I interpret them to be Juniper Hills Formation (Pliocene), as defined by Barrows (1987) and Barrows et al (1985).

Bull (1978), and Bull et al (1979), studied the age and deformation of stream terraces in the San Gabriel Mountains. Bull et al (1979, p. 25-27) estimate the age of soils developed on terraces at three places on the south side of the mountains: they conclude that soils developed on the highest terraces are >0.5 Ma and on the lowest terraces are <1.0 Ka.

The highest (and oldest) gravels that I have observed at Palmdale are on the east side of Little Rock Creek canyon, perched at an elevation of 3,800 ft (1,140 m) (Figure 5, locality D-1). They consist of a patch of water-worn cobbles ~35 m long on a narrow, northeast-trending ridge, 1.1 km northeast of Little Rock Dam (SW¼ SE¼ NE¼ sec. 27, T5N, R11W, SBM). These gravels are inferred to be early to middle Pleistocene in age (~ 0.75-1.0 Ma [?]). The oldest exposed deposits derived from Little Rock Creek canyon may be steeply-dipping boulder conglomerate on the northeast side of the San Andreas fault, 8.5 km southeast of where Little Rock Creek extends northward across the San Andreas fault (Figure 5, locality D-2). This conglomerate, exposed in cuts for 106th St. East (center NW¼ sec. 33, T5N, R10, SBM), may be as old as 1.5-2.0 Ma. Little Rock Creek canyon has existed since 1.0 Ma, and probably developed before ~1.5 Ma. The youngest, slightly perched wash deposits along Little Rock Wash are ≤1.0 Ka.

Barrows et al (1985, p. 114-115, Table 2) date miscellaneous perched alluvial deposits they mapped along the San Andreas fault between Quail Lake and Mile High as ranging from 0.2-0.6 Ma. Meisling and Weldon (1989, Figure 4, p. 110) provide a date of 0.73 Ma for the uppermost Victorville alluvial fan deposits in the Phelan Peak-Cajon Pass area. This date was obtained by paleontologic and magnetostratigraphic techniques. Weldon et al (1993, Figure 4) show deposits they identify as Harold Formation to range in age from ~1.4 to 1.6 Ma at Cajon Pass and to become progressively younger northwestward: ~0.45 to 0.7 Ma at Largo Vista, 30 km to the northwest.

If deposits of the Harold Formation were displaced 2.5 km at the "consensus" rate of 3.5 cm/yr, their implied age is just 70 Ka. If displaced at the long-term rate of 2.0 to 2.5 cm/yr implied by Barrows et al (1985), their age would be ~100 to 125 Ka.

My work consistently shows that the rate of displacement of rocks ≤ 2-3 Ma along the Mojave segment of the San Andreas is in the range of 0.5 to ≤ 1.0 cm/yr. Thus, if Harold deposits are right-laterally displaced ~2.5 km, as I interpret, their age should center around ~0.5 Ma (or ~0.25 Ma if the rate is ~1.0 cm/yr). I infer, therefore, that their age is between ~0.25 and

0.5 Ma. The oldest, partly coalescent Hunt Canyon fan deposits are about the same age.

DISPLACEMENT RELATIONSHIPS

Previous Findings (with Comments)

Noble (1954b, p. 46) concludes that deposits of the Harold Formation are right-laterally displaced about 5 miles (8 km) along the San Andreas fault. Noble (p. 46) further concludes that older alluvium along one stretch of the fault between Valyermo and Pallett Creek is displaced "1 to 2 miles" (1.6 - 3.2 km). Noble (1953) states that the San Andreas fault "is the site...of late Quaternary...strike slip movements aggregating at least 4,000 feet" (1,200 m).

Barrows et al (1985, p. 100-103, 114) interpret that deposits of the Harold Formation are displaced from 8 to 16 km along the San Andreas fault. My detailed mapping, however, shows that deposits southwest of the fault these geologists correlate with alleged displaced counterparts northeast of the fault are not related. For example, Barrows et al (1985, p. 101) interpret that deposits 2 km east of Little Rock Wash, northeast of the fault, are displaced 8 km from equivalent deposits of their Pelona-Schist clast member at the type locality southwest of the fault. The deposits near Little Rock Wash have the same clast composition as the Pelona Schist-clast member of the Harold, but are lithified and highly deformed and, apparently, much older. I interpret that the breccia-conglomerate is part of the Juniper Hills Formation (middle-late Pliocene [?]) and is right-laterally displaced 4.5 to 9 km (Figures 7a-b, features 5A-B).

Brown (1990, p. 98-103) reviews studies of Quaternary deformation along the San Andreas fault in southern California by Wallace (1949), Noble (1954b), Barrows et al (1985; Palmdale-Juniper Hills area), and other geologists. In summary, Brown (1990, p. 107) states: "At a slip rate of 3.5 cm/yr, the

> San Andreas has displaced middle Pleistocene (1 Ma) outcrop belts and major structures by about 35 km, effectively creating - on opposite sides of the fault - two independent structural domains, each of which responds differently to its new structural setting."

In Figure 4.22 (p. 108-109) accompanying Brown's article, however, the "average Quaternary slip rate" for the southern California segment of the fault is shown as 2.0-3.0 cm/yr; and the central California rate is given as >3.0 cm/yr.

Weldon et al (1993, p. 162) interpret that displacement along the Mojave segment of the San Andreas fault during Pleistocene time was ~60 km. Based on the consensus slip rate of 3.5 cm/yr, therefore, displacement of deposits 0.45 - 1.6 Ma at Cajon Pass that these geologists identify as Harold Formation is implied to be in the range of ~15 to 53 km. The deposits at Cajon Pass, however, bear no relation to those at Palmdale.

Sharp and Silver (1971) interpret that certain perched gravels in the southeastern Palmdale area have been displaced ~8 km along the San Andreas fault. Likewise, Barrows et al (1985, p. 107) conclude that their "boulder gravel of Little Rock Creek" (Plates 1F, 1G: Qbl) is displaced ~8 km. I interpret, instead, that the gravels were transported southeastward along the fault for nearly 8 km before being carried northeast into the desert (Figure 5, locality A). Evidence for my interpretation is provided by paleocurrent structures in the gravels exposed in cuts for Mount Emma Road within 1 km east of the San Andreas (Weber, 1998b, unit Qow_1). A similar scenario exists today where Amargosa and Anaverde creeks flow southeast along the fault, 13 and 3 km respectively, then extend northeast into the desert (Figure 5, locality A). I conclude that the Little Rock Creek gravels carried northeast have been displaced <2 km, not 8 km.

Dibblee (1967, p. 112) estimates that older alluvium at Palmdale derived from Pelona Schist is displaced "about 7 miles" (11 km); likewise, I interpret that these deposits were transported southeastward along the San Andreas rift. The distance stream deposits exist away from their source on the opposite side of the fault is commonly not a measure of their lateral displacement.

Present Findings

Right-lateral displacement along the San Andreas fault of geologic units ranging in age from late Pliocene (2-3 Ma [?]) to late middle Pleistocene (0.2 Ma [?]) is summarized in Figures 7a-b (features 1A-B to 6A-B).

Harold Formation and additional deposits at Palmdale. Geologic relationships depicted in Figures 2a-b and 6 show that the distinctive marble-clast bearing Pelona Schist-clast member of the Harold Formation at Palmdale has been displaced ~2.5 km (Figures 7a-b, localities 2A-B).

Displacement of two other varieties of older, perched alluvium northeast of the fault at Palmdale can also be estimated, even though no counterparts exist southwest of the fault.

(1) Very coarse deposits with a distinctive clast lithology exist just north of Harold deposits at 40th St. East, south of the California Aqueduct (N½ SW¼ SW¼ sec 8, T5N, R11W, SBM)(Figure 8, Qoa; Weber, 1998b, Qoa_{6b}). Clasts reaching 50-75 cm in maximum dimension consist mainly of volcanic rocks of the Vasquez Formation, syenite, and Pelona Schist. Very sparse clasts of resistant sandstone (to 25 cm), originally derived from strata of the San Francisquito Formation, were recycled into these deposits from local upper Tertiary conglomeratic rocks within 1-2 km north

of the intersection of Sierra Highway and Pearblossom Highway (Figure 8, RSS). Based on their apparent direction of transport, I estimate that these deposits are displaced ~2 km relative to their source terrane.

(2) Several small patches of alluvium are perched along the west side of a small, north-directed canyon containing 42nd Street East (SW¼ SW¼ SE¼ sec. 8, T5N, R11W, SBM) (Weber, 1998b, Qoa_{11}). Clasts include Lowe Granodiorite, Pelona Schist, syenite, marble, and Vasquez volcanics. These deposits are displaced ~1.5 km from their apparent source southwest of the San Andreas, an area that includes the intersection of Barrel Springs Road and the California Aqueduct (NW¼ SW¼ sec. 7, T5N, R11W, SBM).

Shoemaker Gravel and additional coarse gravels between Juniper Hills and Mile High. Four well-defined geologic units of apparent middle Pleistocene age are right-laterally displaced along the San Andreas fault between Juniper Hills and Mile High. These include (1) Shoemaker Gravel, (2) very old alluvium of Brainard Canyon, (3) very coarse gravel of Big Rock Creek, and (4) perched alluvial-fan deposits directed northeast from Pinyon Ridge.

(1) Shoemaker Gravel (Noble, 1954a) consists of coarse, mostly flat lying, but deeply eroded gravel on the northeast side of Shoemaker Canyon, northeast of the San Andreas Fault. The deposits are well exposed in cuts for Big Pines Highway, especially along the segment that traverses the northeast side of Shoemaker Canyon, 1.5 km east-southeast of Big Rock Creek. In the lowest cuts here, adjacent to the San Andreas fault, the gravels can be observed to dip moderately to steeply northeast.

Clasts consist nearly wholly of plutonic and metamorphic rocks, including Lowe Granodiorite, crenulated gneiss, massive pale granitic rocks, and other types derived mostly from the San Gabriel Mountains. Clasts of unique polka-dot granite are rare. The largest subrounded granitic boulders are about 1.25 m in diameter.

Shoemaker Gravel was mostly derived from the plutonic rocks of the San Gabriel Mountains. It was transported northward and northeastward to the San Andreas fault within the Pallett Creek-Holmes Creek drainage. From here the sediments were transported eastward and southeastward, coalescing with very coarse sediments derived from Big Rock Creek canyon. The combined deposits were transported as far as Cajon Pass, a distance from Pallett Creek of 45-50 km. Isolated patches exist in the upland area adjoining the San Andreas both southeast and northwest of Mescal Creek canyon, (for example, Figure 12, locality 6, Ball Flat). The deposits at Ball Flat have an approximate elevation of 6,250 ft, 2,450 ft higher than the site of deposition at the San Andreas fault (3,800 ft).

FIGURE 7a

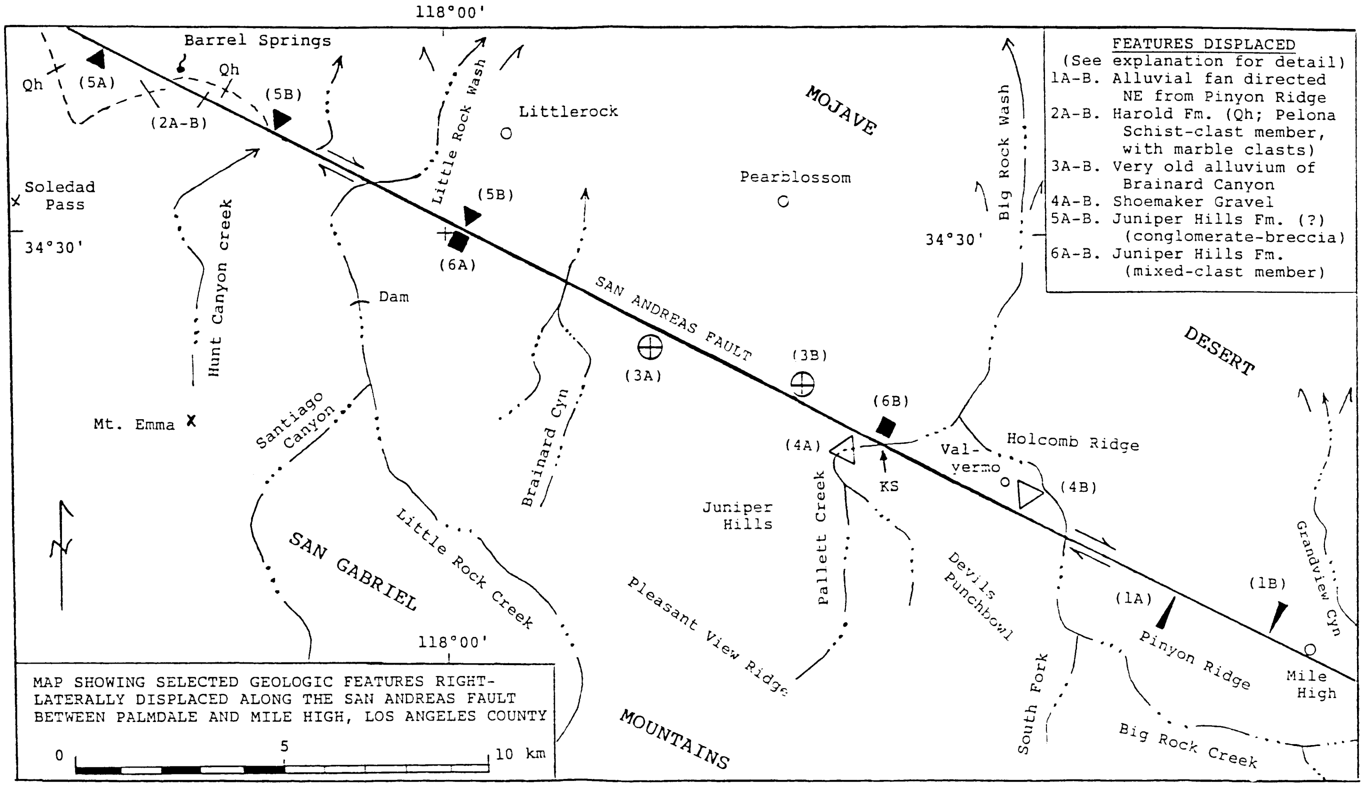

FIGURE 7a. Map along the San Andreas fault between Palmdale and Mile High showing displacement of geologic features 1A-B to 6A-B. For displacement data, see Figure 7b. SYMBOL: KS, Kerry Sieh trenching site.

RIGHT-LATERAL DISPLACEMENT OF THE PLEISTOCENE HAROLD FORMATION
AND RELATED DEPOSITS ALONG THE SAN ANDREAS FAULT,
PALMDALE REGION, SOUTHERN CALIFORNIA

ROCK UNIT (Inferred Age)	RIGHT-LATERAL DISPLACEMENT, SAN ANDREAS FAULT (KM)
1A-B. ALLUVIAL FAN, PINYON RIDGE (Late middle Pleistocene)	(2.3 km)
2A-B. HAROLD FORMATION (Middle Pleistocene)	(~2.5 km)
3A-B. VERY OLD ALLUVIUM OF BRAINARD CANYON (Middle Pleistocene)	(3-5 km)
4A-B. SHOEMAKER GRAVEL (Middle Pleistocene)	(≤ 5 km)
5A-B. JUNIPER HILLS FM.(?); Pelona Schist-syenite clast breccia-conglomerate (QTjb) (Latest Pliocene[?])	(~9.0 km, maximum)
6A-B. JUNIPER HILLS FM.; "mixed-clast" and "arkosic basal-breccia" member of Barrows and others, 1985 (QTjm, Qtja) (Middle [?] Pliocene)	(~12 km)

FIGURE 7b. Right-lateral displacement of selected rock units along the San Andreas fault, Palmdale southeast to Mile High. For detail see explanation.

EXPLANATION
(FIGURE 7b)

1A-B. Contact between distinctive lithofacies of perched alluvial fan deposits directed NE from Pinyon Ridge. Offset 2.3 km (Figures 8a-b).

2A-B. Pelona Schist-clast member of Harold Formation, containing angular to subrounded fragments of marble. Displacement ~2.5 km (Figures 2a-b, 6).

3A-B. Coarse, very old alluvium derived from a source terrane SW of the San Andreas (SAF) at Brainard Canyon and vicinity; deposits were transported SE along NE side of fault. Inferred displacement 3-5 km.

4A-B. The source SW of the SAF for Shoemaker Gravel is the Pallett Creek - Holmes Creek drainage. Deposits were transported SE and E along the NE side of the SAF. The displaced source point on the NE side of the fault is interpreted to be 1 km SE of Valyermo. Inferred displacement $\leq$ 5 km. (Also see Figure 12, localities 1-3.)

5A-B. Juniper Hills Formation(?), Pelona Schist-syenite clasts breccia-conglomerate member. Rocks SW of SAF exist between Una Lake and Pearblossom Highway (Palmdale 7.5-minute quadrangle); NE side of fault, between 47th Street East (Palmdale quad) and a locality 700 m SE of quadrangle boundary (Littlerock quad). Displacement 4 to $\leq$9 km.

6A-B. Juniper Hills Formation, mixed-clast member (Barrows and others, 1985). Distinctive conglomeratic rocks. Rocks SW of SAF, E edge of Palmdale quadrangle (Weber, 1998b); NE of fault, exposed in low, ESE-directed ridges 250 m N of Pallett Creek Road (Juniper Hills quadrangle; center NW¼ SW¼ SW¼ sec. 1, T4N, R10W, SBM; 3800-foot contour). At both localities, the mixed-clast rocks are bounded on the N by granitic rocks (Weber, 1998b, gr_2). Displacement ~12 km.

FIGURE 8

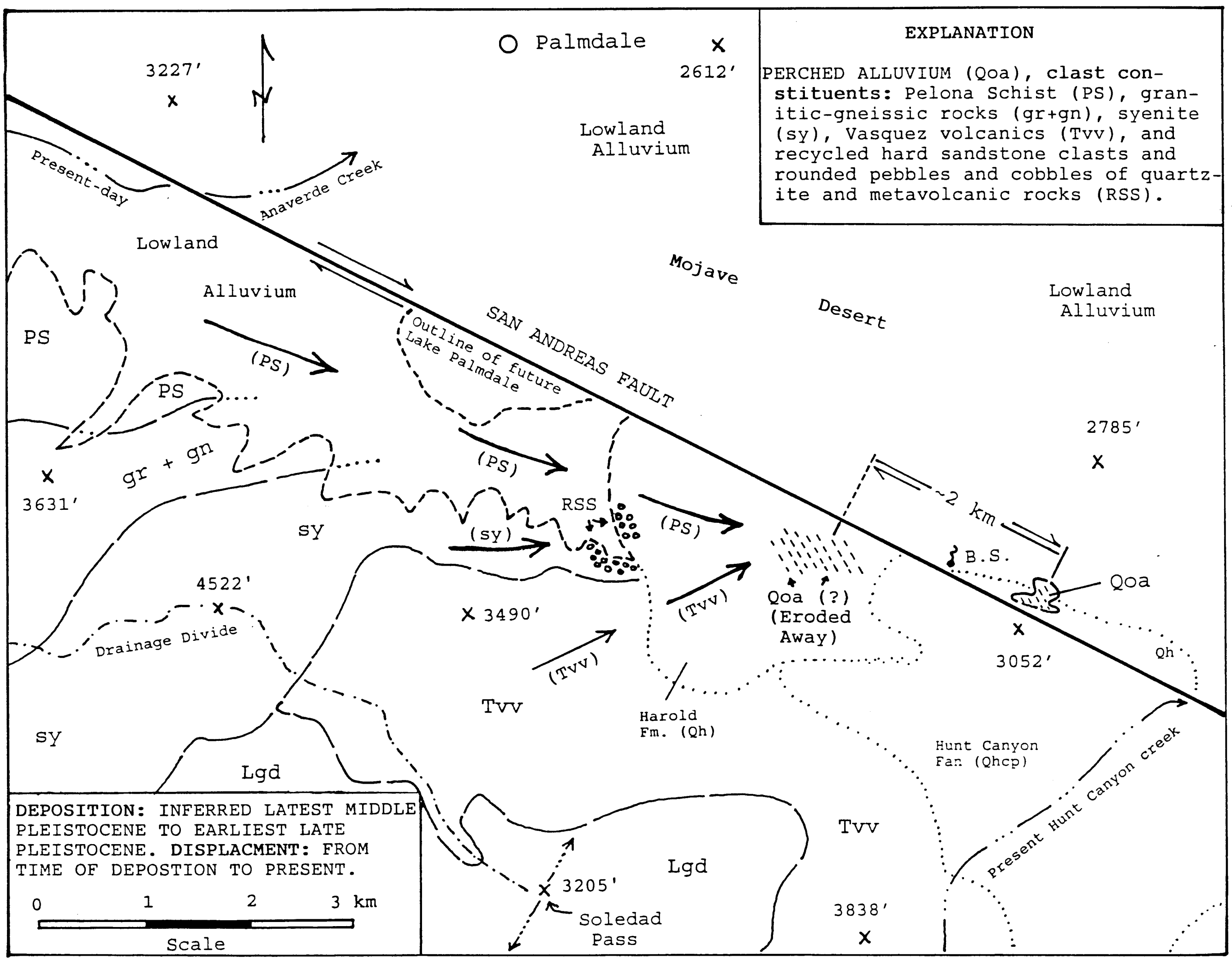

FIGURE 8. Distinctive perched alluvial deposits (Qoa) on northeast side of San Andreas have no exact counterpart on the southwest side (Weber, 1998b, Qoa_{6b}). Their source, however, includes conglomeratic rocks (RSS) with abundant large clasts of resistant sandstone within 1 to 2 km north of the intersection of Sierra Highway and Pearblosson Highway. Arrows show transport direction of sediments. Estimated displacement is ~2 km.

Artificial exposures in Shoemaker Gravel excavated for a small dam 500 m northeast of Mountain Brook Ranch (Valyermo quadrangle) disclose a paleocurrent direction for the gravel of east-northeast (Figure 12, locality 2). This direction projects backward to a site 1 km southeast of Valyermo (Figure 7a, locality 4b). I infer that this is the displaced site of deposition on the northeast side of the San Andreas, ~5 km from its source at Pallett Creek on the southwest side. Right-lateral displacement is inferred, therefore, to be ≤ 5 km (Figures 7a-b, localities 4a-b).

(2) Very coarse gravels derived from Big Rock Creek canyon have a clast composition distinctively different from that of Shoemaker Gravel. For example, clasts of Pelona-type schist and hard sandstone derived from strata of the San Francisquito Formation are relatively common in the Big Rock Creek deposits. Subrounded boulders of plutonic rocks reach nearly 4 m in maximum dimension. The Big Rock Creek gravels, clearly on the northeast side of the San Andreas, extend southeast from a locality ~3 km southeast of the mouth of the canyon. It is inferred, therefore, that they are displaced ~3 km, apparently less than Shoemaker Gravel, with which they appear to be partly coeval.

(3) Perched alluvial fan deposits directed northeast from Pinyon Ridge extend across the San Andreas fault and are right-laterally displaced along it (Figures 7a-b, localities 1A-B; Figures 9a-b). The area is 15 km northwest of Wrightwood, within the Valyermo 7.5-minute quadrangle. The deposits were mainly derived from gneiss of Pinyon Ridge (pgn; Qofg facies); the westernmost deposits, however, were derived partly from the gneiss and partly from rocks of the San Francisquito Formation (Tsf; Qofgs facies)(Figure 9b, thick arrows). The contact between these two facies is right-laterally offset 2.3 km (Figure 9b).

The fan deposits at their western edge (Figure 9a, locality 1), southwest of the San Andreas, are perched 250 ft (75 m) above the floor of Shoemaker Canyon, 300 m to the north. Northeast of the fault, the fan was deposited upon a moderately eroded surface developed on essentially coeval mid-Pleistocene units: Shoemaker Gravel and very coarse gravel derived from Big Rock Creek canyon. Bedding within these two units and the fan deposits is essentially horizontal except where the deposits are deformed within the inner San Andreas zone. In some exposures along Big Pines Road, near the principal trace of the fault, the deposits are very steeply dipping to vertical. I infer that the fan deposits are late-middle Pleistocene, possibly in the range of 0.25 to 0.4 Ma.

(4) Coarse, deeply eroded alluvium with a distinctive clast composition extends for 3 km along the northeast side of the San Andreas fault in the vicinity of Longview Road, Juniper Hills (from center W edge sec. 2 SE to NW¼ SE¼ sec. 1, T4N, R10W, SBM) (Figures 7a-b, localities 3A-B). These deposits were derived

FIGURE 9a

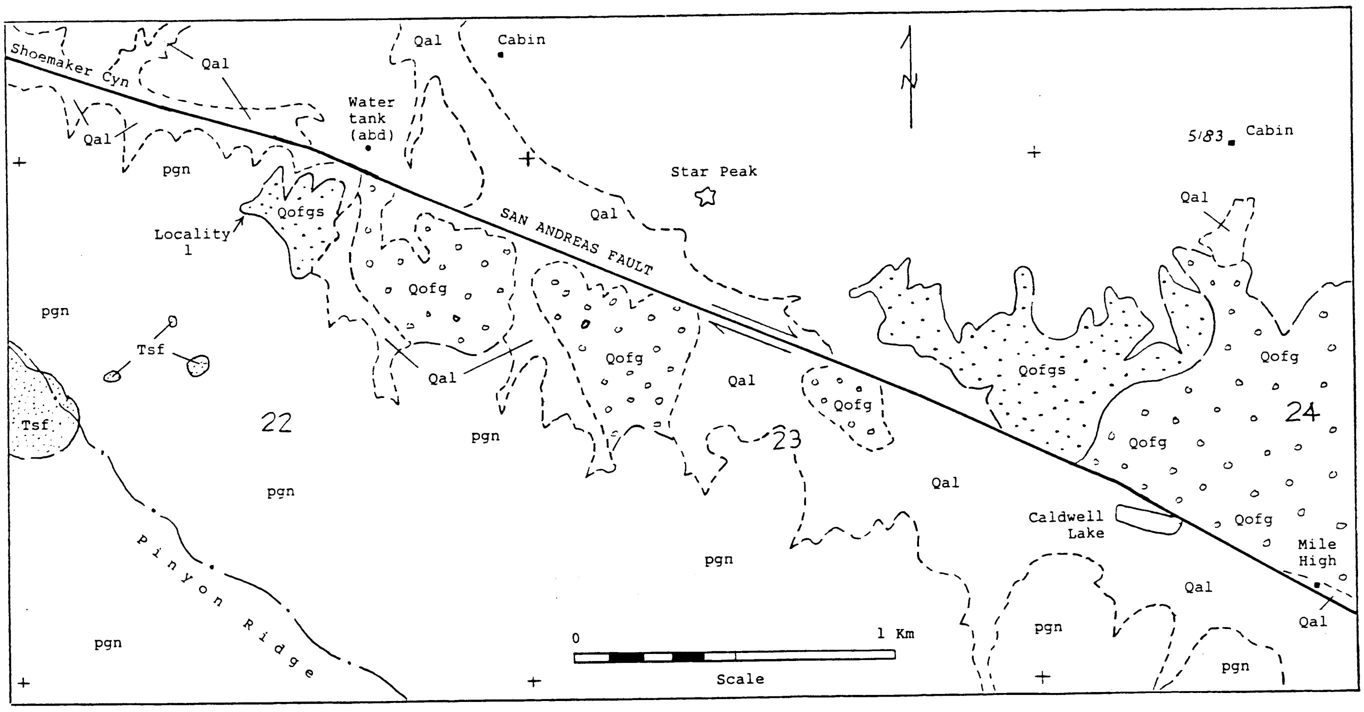

FIGURE 9a. Geologic outline map along the San Andreas fault between Shoemaker Canyon and Mile High, Los Angeles County. UNITS: pgn, gneiss of Pinyon Ridge; Tsf, San Francisquito Formation (marine shale, sandstone, conglomerate); Qofg, northeast-directed alluvial fan deposits consisting of coarse, angular debris derived from pgn; Qofgs, similar to Qofg, mixed with coarse fragments of Tsf; Qal, late Pleistocene-Holocene alluvium. Locality 1: Qofgs is perched 75 m above floor of Shoemaker Canyon, 300 m to north. Topographic data are from Valyermo 7.5-minute quadrangle published by U.S.Geological Survey.

FIGURE 9b

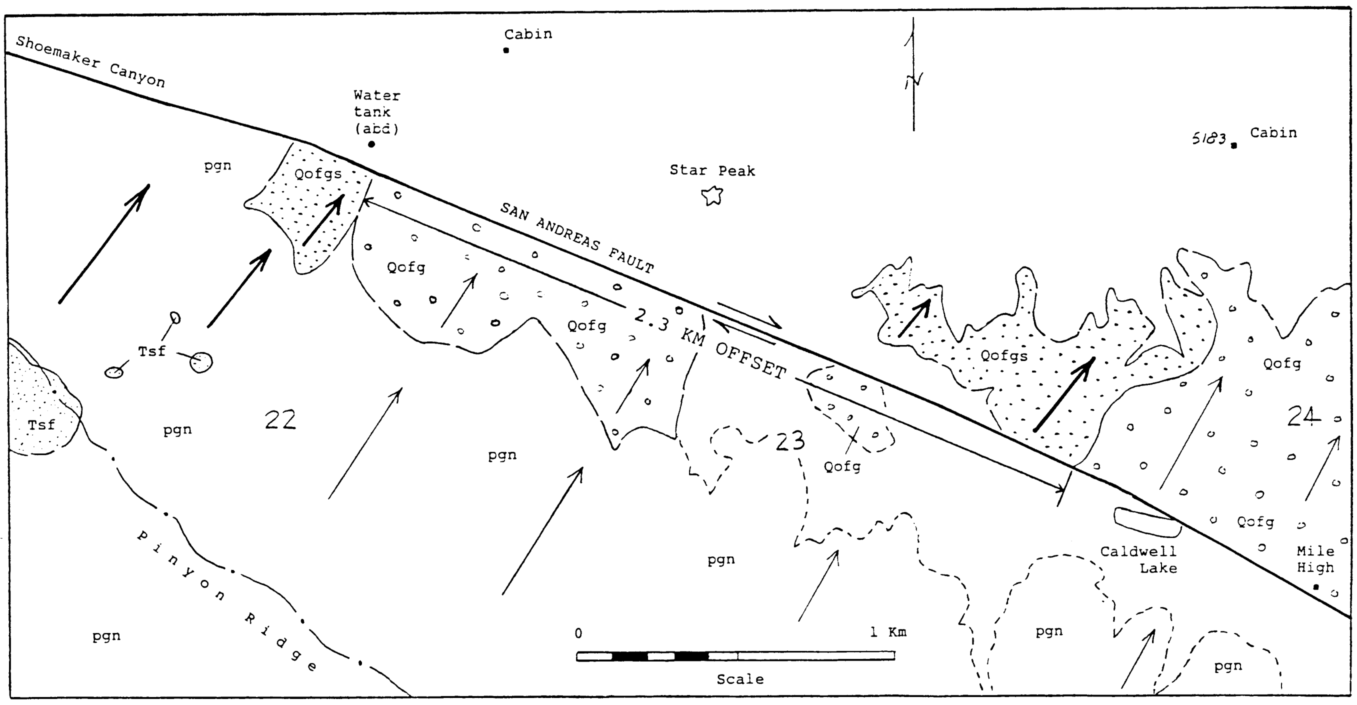

FIGURE 9b. Simplified version of Figure 9a showing contact between Qofg and Qofgs right-laterally offset 2.3 km. Thick arrows show direction of deposition of Qofgs; thin arrows, Qofg.

from a source terrane southwest of the San Andreas that included ancestral Brainard Canyon. The deposits appear to be right-laterally displaced between 3 and 5 km.

DISCUSSION

The Hungry Valley Formation Problem

The fundamental problem with "mainstream" estimates of displacement of Pleistocene deposits along the San Andreas fault between Tejon Pass and Cajon Pass is that these estimates are closely related to the solution of another problem: origin and displacement of the nonmarine, largely Pliocene Hungry Valley Formation, southwest of the San Andreas fault in Ridge Basin.

In a scenario developed by Crowell (1982), clastic constituents of the Hungry Valley Formation are said to have been derived from the western San Bernardino Mountains, now 150-170 km to the southeast. Crowell perceives that Ridge Basin lay southwest of these mountains in latest Miocene time, across the trace of the newly developing strand of the San Andreas fault. Beginning ~5 Ma, sediments from the mountains were shed southwestward across the trace into the basin, creating the Hungry Valley Formation. The two terranes are interpreted to have reached their present locations as a result of 150-170 km displacement on the fault that began during, or soon after, deposition of the Hungry Valley sediments.

Matti and Morton (1993), Weldon et al (1993), Powell (1993), and Saddler (1993) interpret further that the Hungry Valley Formation was derived mostly from the clastic constituents of the nonmarine Crowder Formation, in the westernmost San Bernardino Mountains. My mapping in northern Ridge Basin (1988, 1998a), and at Cajon Pass (unpublished, 1993-1997), shows that the Crowder's clastic constituents are not related to those of the Hungry Valley Formation, so could not have been their source.

My interpretation is that the youngest rocks of the Hungry Valley Formation are right-laterally displaced about 10-15 km (Figures 10a-c). The basal unit of the upper member of the Hungry Valley Formation (Weber, 1998a; $TQhu_1$) consists of coarse conglomerate with distinctive clasts of white marble. Similar rocks are exposed in cuts for Pine Mountain Road on the northeast side of the San Andreas Fault in Oakdale Canyon, 3.5 km northwest of Three Points. Apparent displacement is ± 15 km (Figure 10b). Barrows et al (1985, p. 96-98, 114) interpret a similar displacement relationship.

Deposits of probably the youngest subunit of the upper member of the Hungry Valley Formation ($TQhu_4$), within Ridge Basin, have a clast lithology very similar to that of the Sand Hills beds (TQsh), 40 km to the northeast, across the San Andreas Fault. Both units contain clasts of Pelona-type schist derived from the Tehachapi Mountains and clasts of a variety of volcanic rocks derived from the Rosamond area. Paleocurrent structures within the Sand Hills beds, where exposed along the Los Angeles Aqueduct road, indicate they were transported west-southwest (Figure 10c). Exposures in rocks of the $TQhu_4$ unit of the Hungry Valley Formation indicate they were deposited generally westward. Apparent displacement is ± 10 km (Figure 10c).

Pleistocene Displacement/Slip Rate

Displacement of 150-170 km along the Mojave Desert segment of the San Andreas since 4 to 5 Ma equates with the consensually accepted "slip" rate for the fault of 3.5 cm/yr. This scenario further requires that right-lateral displacement ("right slip") since the beginning of Pleistocene time (~ 1.8 Ma) is ~60 km. Weldon et al (1993, p. 162) state: "Sixty kilometers of right-lateral slip occurred across the San Andreas fault zone during Quaternary time." Weldon et al (1993, p. 165) state further: "Sediments shed northeastward off the central San

> Gabriel Mountains across the San Andreas fault and onto the floor of the western Mojave Desert, provide a continuous record of Pleistocene fault displacement at a rate of ~3.5 cm/yr."

Brown (1990, p. 107) states: "At a slip rate of 3.5 cm/yr, the San Andreas has displaced middle Pleistocene (1 Ma) outcrop belts and major structures by about 35 km..." Such a large slip rate, however, is not compatible with known geologic relationships mapped by Noble (1953, 1954a-b), Barrows (1987), and Barrows et al (1985, Plates 1A-1H). My mapping further indicates that displacement of deposits ~2-3 Ma in the Palmdale-Juniper Hills and Frazier Mountain - Quail Lake areas is in the range of 10-20 km (Weber, 1998a). Perched alluvium in the Cajon Pass area, including the youngest Victorville fan deposits, appears to be displaced ~5 to ≤10 km relative to its source terrane southwest of the fault, mainly Pelona-type schist of the Lone Pine Canyon-Wrightwood region.

Foster (1982, p. 72) estimates that Shoemaker Gravel is right-laterally displaced 10-12 km along the San Andreas fault. If deposits in the Phelan Peak-Cajon Pass area identified as Shoemaker Gravel are ~1.0 Ma (Weldon et al, 1993, Figure 4), Foster's interpretation implies a displacement rate of ~1.0 to 1.2 cm/yr, much smaller than the overall consensus of 3.5 cm/yr or the 2.0 to 2.5 cm/yr rate implied by Barrows et al (1985, p. ix, 111-119). My mapping indicates that Shoemaker Gravel is displaced ≤ 5 km (Figures 7a-b, localities 4A-B).

FIGURE 10a

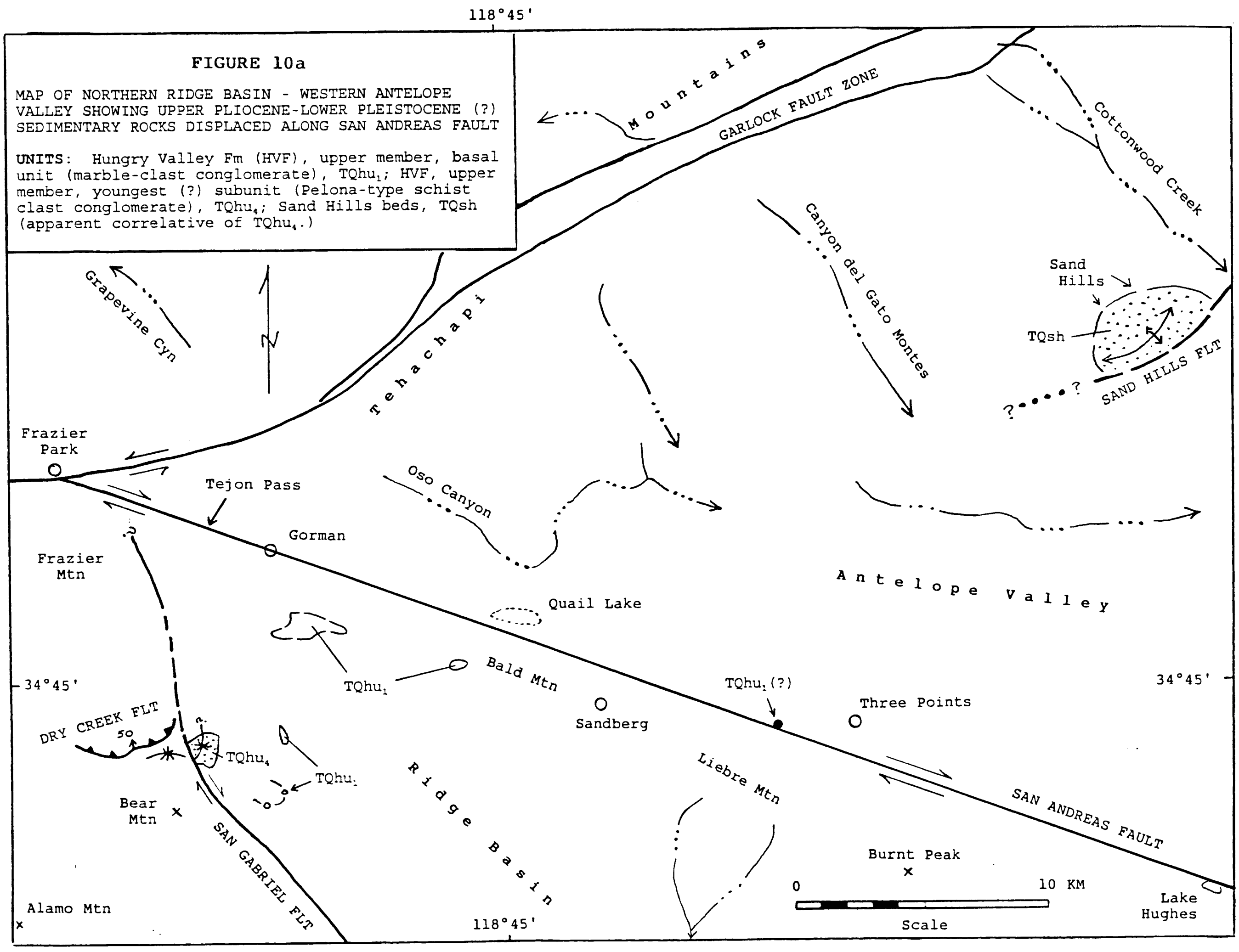

FIGURE 10a. Map of northern Ridge Basin - western Antelope Valley showing relationship of younger rocks of Hungry Valley Formation, Ridge Basin, to Sand Hills beds, northeast of San Andreas fault (geologic data from Weber, 1998a). The clast composition of the Sand Hills beds (TQsh) is very similar to that of the $TQhu_4$ unit of the Hungry Valley Formation, probably the youngest rocks (1-2 Ma [?] of the Hungry Valley Formation. The basal unit ($TQhu_1$) of the upper member of the Hungry Valley Formation may have a counterpart on the northeast side of the fault, as exposed in north-facing cuts for Pine Canyon Road, 3.5 km west-northwest of Three Points. See Figures 10b-c for displacement relationships.

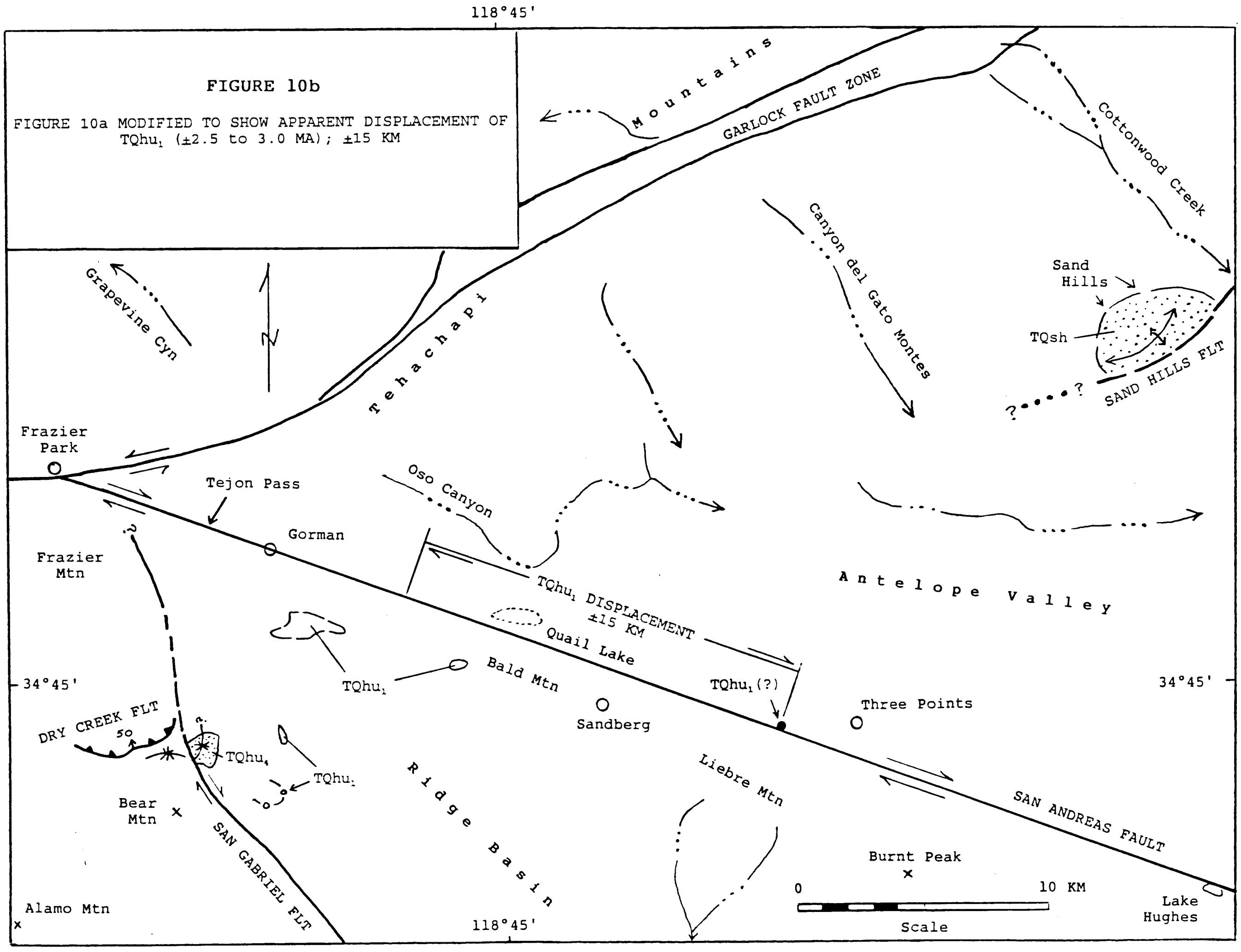

FIGURE 10b. Figure 10a adapted to show apparent right-lateral displacement along the San Andreas fault of basal beds ($TQhu_1$) of the upper member of Hungry Valley Formation, relative to similar rocks northeast of the fault near Three Points. Displacement is estimated to be ± 15 km. A similar displacement relationship was described by Barrows and others (1985).

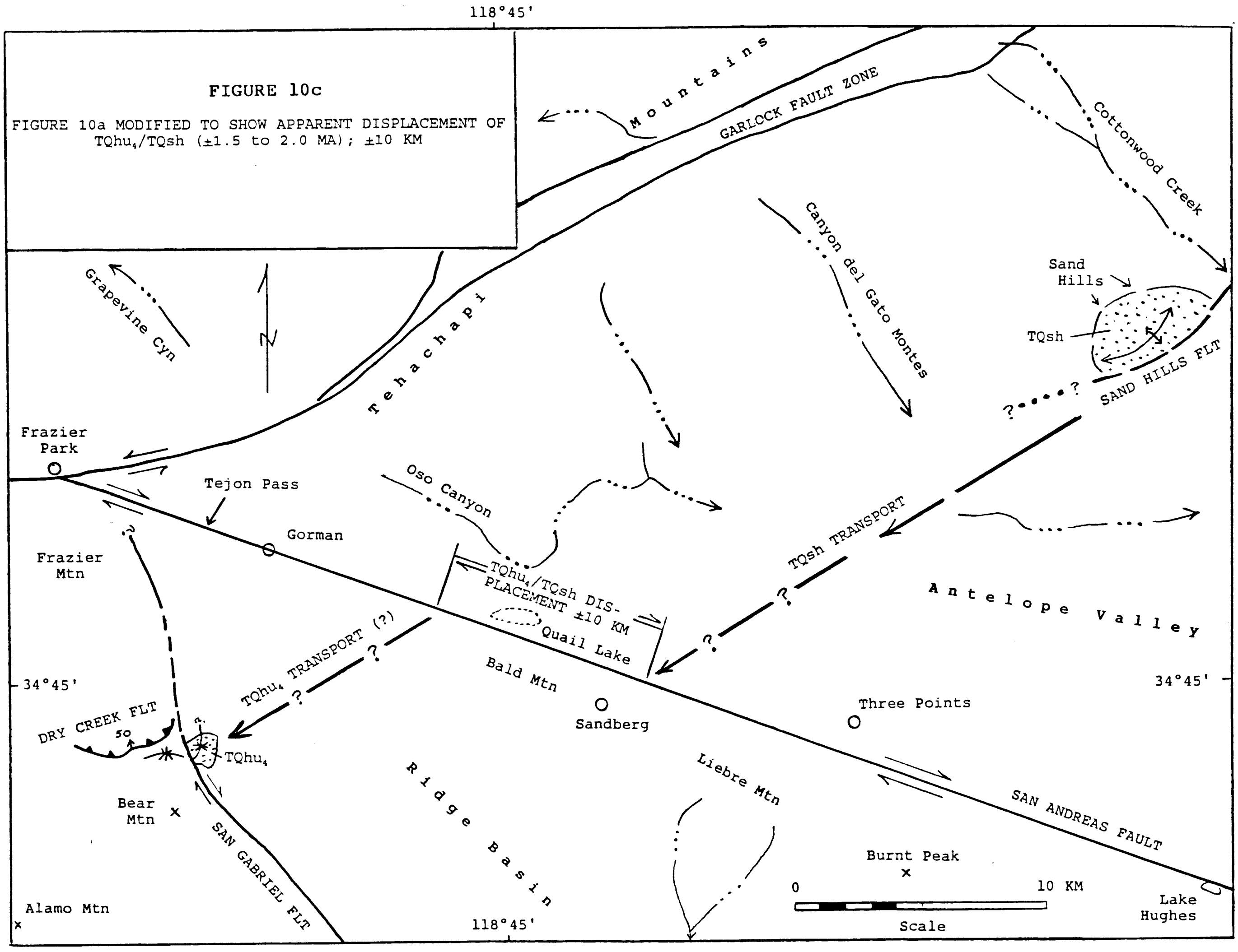

FIGURE 10c. Simplified version of Figure 10a showing displacement relationships involving subunit $TQhu_4$ of the Hungry Valley Formation and the Sand Hills beds. Paleocurrent structures within the Sand Hills beds (TQsh) indicate that these sediments were transported west-southwest (arrows), probably along the trace of the Sand Hills fault. The site where the sediments crossed the fault appears to be right-laterally displaced ±10 km.

Barrows et al (1985, p. 104-105) conclude, as I, that the source of Shoemaker Gravel is the ancestral Pallett Creek drainage; they interpret that the gravel has been displaced 7-8 km along the San Andreas. Barrows et al (1985, p. 107-108) additionally interpret that their "boulder gravel of Big Rock Creek" (my "very coarse gravel of Big Rock Creek") was deposited on Shoemaker Gravel; they conclude that the Big Rock Creek deposits are displaced between 3 and 5 km. My mapping shows that Shoemaker Gravel and the Big Rock Creek deposits are partly coeval, and that Shoemaker is displaced ≤ 5 km.

In the Frazier Mountain-Quail Lake area, deposits of perched alluvium are displaced ~0.5 km along the San Andreas fault (Weber, 1998a). Barrows et al (1985, p. 106) similarly find that older alluvium in the Bald Mountain-Liebre Mountain area, a few km southeast of Quail Lake, is displaced along the San Andreas "from a few meters to 0.5 km." This contrasts with their interpretation of relationships in the Palmdale-Juniper Hills area (1985, p. 106-111, 115) that upper Pleistocene boulder gravels are displaced 2 to ≥ 8 km and that the Harold Formation is displaced 8 to 16 km. If their use of the name Harold Formation for deposits on the northeast side of the fault had been restricted to deposits similar to those at the type locality southwest of the fault, their estimate of displacement would necessarily have been < 5 km.

The Pinyon Ridge fan deposits southwest of the San Andreas are perched 75 m above the bottom of Shoemaker Canyon, 300 m to the north (Figure 9a; Locality 1). The deposits are deeply eroded. Their age is inferred to be in the range of 0.25 to 0.4 Ma. If ~0.25 Ma, their slip rate is slightly less than 1.0 cm/yr, about the rate estimated by Sieh (1984a-b) for upper Holocene deposits at his trenching site (next section). Further, the Pallett Creek site is in the general vicinity of where Shoemaker Gravel was deposited eastward across the San Andreas. I estimate that this locality on the opposite side of the fault is now ~1 km southeast of Valyermo, displaced roughly 4 km. I infer that the age of Shoemaker Gravel is in the range of 0.5 to 0.75 Ma. If 0.5 Ma, and displaced 4 km, its slip rate is 0.8 cm/yr, roughly what Sieh (1984a-b) finds for upper Holocene deposits.

Holocene Displacement/Slip Rate

At its closest point, the alluvial fan at Pinyon Ridge right-laterally offset 2.3 km is 8 km southeast of where the San Andreas fault at Pallett Creek was trenched by Sieh (1984a,b; Sieh and others, 1989). The trenching site is a flat, slightly eroded surface on the north side of deeply incised Pallett Creek. The site is on the principal active trace of the San Andreas fault (Barrows et al, 1985, Plate 1G). Sieh (1984, p. 7642) estimates that major re-entrenchment of the creek occurred "in about 1050 and again in 1910."

The surface, which broadens to the west-northwest, is adjoined by remnants of higher, much older (late middle [?] Pleistocene) erosional surfaces, partly overlain by older alluvium. Sieh et al (1989) have documented ten fault-rupture events, dating from about 1000 A.D. to 1857. Sieh et al (1989, p. 352, 364-365) calculate that the average interval between these events is 132 years.

Sieh (1984, p. 7660) calculates that the slip rate for the San Andreas fault at Pallett Creek in late Holocene time is about 9 mm/yr, "anomalously low" in his words. Following are excerpts from his explanation of this problem (Sieh, 1984, p. 7660).

> "Taken together, the major faults exposed at the Pallett Creek site accumulated about 10 m of slip between about 735 and 1857 A.D. This yields an average slip rate of only 9 mm/yr, a value that is only one third to one fourth of Holocene slip rates determined elsewhere along the San Andreas fault [Sieh and Jahns, 1984; R.J. Weldon and K. Sieh, unpublished manuscript, 1984]. Likewise, the offset attributed to the 1857 earthquake at the site is a mere 2 m, whereas 3-4.5 m have been attributed to this event on the basis of offset stream channels nearby [Sieh, 1978b] (*herein: Sieh, 1978*)."

> "To explain these unexpected discrepancies, one cannot call upon unexcavated major traces because this possibility has been ruled out.. It is reasonable to hypothesize that the Northern Nadeau fault, a short, discontinuous, secondary, late Holocene structure.., is contributing a millimeter or two per year. In addition, the collection of minor faults within the excavation may reasonably be allowed a couple of millimeters per year...."

> "Minor faulting and nonbrittle folding within the site and slip on the Northern Nadeau fault can probably account for no more than several millimeters per year of the 15 or 25 mm/yr discrepancy...."

> "Taken together, minor faulting and warping at the latitude of the site could conceivably provide the additional 15-25 mm/yr of right-lateral slip that would be required to bring the slip rate up to the levels documented at sites to the northwest and southeast. However, further investigation is clearly needed to account adequately for this discrepancy."

There is no doubt that substantial right-lateral displacement has taken place along the San Andreas during Holocene time. Small northeast-directed gulches and creek beds of Holocene age have been continually offset along the San Andreas during Holocene time as can be observed at selected localities (Sieh, 1978; Barrows et al, 1985). For example, at a locality 850 m northwest of Longview Road, offset remnants of a shallow, northeast-directed gulch can be observed on the northeast side of the fault, becoming fainter southeast (Figure 5, locality F; Figure 11). This locality is 2 km northwest of the Sieh trenching site. These are features also described by Barrows et al (1985, p. 66).

Sieh (1984, p. 7660) suggests that additional slip to his 9 mm/yr may be taken up on the Northern Nadeau fault (Barrows and others, 1985, Plate 1G) and other faults of the San Andreas zone. My mapping indicates that right-lateral displacement regionally since mid-Pleistocene time has occurred only on the San Andreas fault *(sensu stricto)*.

Geologic relationships that I have observed mapping along the San Andreas zone between Lake of the Woods and Quail Lake, and between Palmdale and Cajon Pass, indicate further that the only significant lateral displacement to have occurred on faults of the San Andreas zone since 4-5 Ma has been on the San Andreas fault (*sensu stricto*). I estimate that total right-lateral displacement since 4-5 Ma is no more than ~50 km, and probably is in the range of 25 to 50 km, a displacement rate of 0.5 to 1.0 cm/yr (Weber, 1998a).

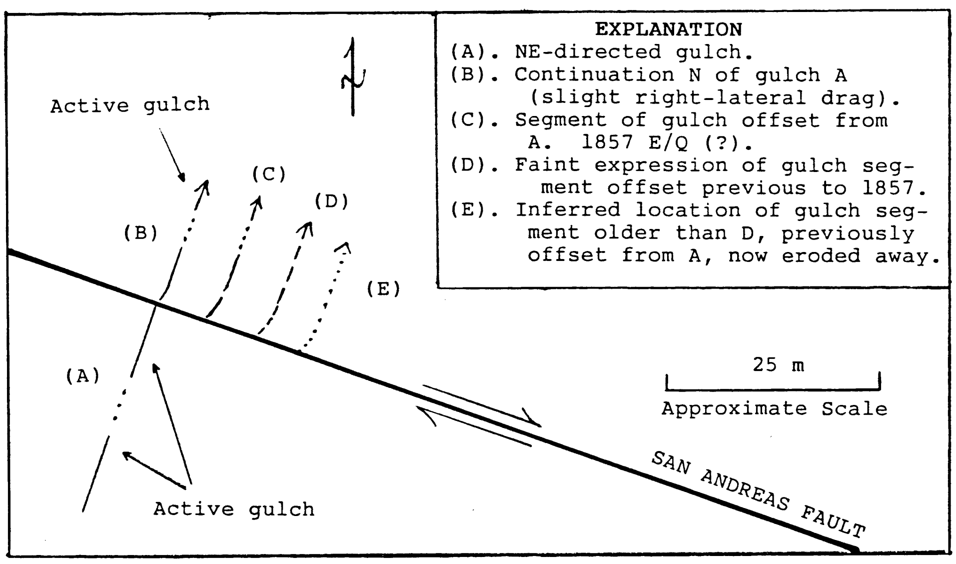

FIGURE 11. Pictorial diagram showing right-lateral offset along the San Andreas of a northeast-directed gulch 850 m northwest of Longview Road, just southeast of the "E" in the word "ZONE," Juniper Hills quadrangle (photorevised 1988).

CONCLUSIONS

It is unfortunate that Noble (1954) extended use of the name Harold Formation from Palmdale to Cajon Pass, and that others have followed (Dibblee, 1967; Woodburne and Golz, 1972; Foster, 1980, 1982; Bortugno and Spittler, 1986; Meisling and Weldon, 1989; Weldon et al, 1993) (Figure 1, Qh vs "Qh"). The name should be used only for distinctive alluvial, colluvial, and lacustrine deposits in the south Palmdale area that commonly contain clasts of locally derived Pelona Schist, syenite, gneissic-granitic rocks and white marble. The Harold Formation is minimally deformed except at contacts with active faults of the San Andreas zone; and its provenance and clast assemblage are unique. Deposits southeast of Palmdale are not correlative.

Older alluvium displaced along the San Andreas fault should be identified with canyons or other terrain features southwest of the fault from which it was derived. For example, dissected, coarse older alluvium along the northeast side of the fault at Longview Road, Juniper Hills, clearly is derived from the ancestral Brainard Canyon area. I call these deposits "very old alluvium of Brainard Canyon." They were identified as Harold Formation by Noble (1954a) and Barrows et al (1985, Plate 1G), but are not related to the type Harold Formation.

Additionally, most stream deposits transported northeast from the San Gabriel Mountains to the San Andreas have been transported along its rift for varying distances before being carried northward into the Mojave Desert. Seldom have deposits been transported directly across the fault into the desert. Most commonly they have been transported southeastward from Little Rock, Big Rock, and other creeks. Failure to recognize this phenomena in past work has resulted in exaggeration of displacement of older stream deposits.

Mid Pleistocene to upper Middle Pleistocene sedimentary deposits from Palmdale southeast to Big Pines have been right-laterally displaced at a rate of 0.5 to ≤ 1.0 cm/yr. These deposits include the Harold Formation, Shoemaker Gravel, and very old alluvium of Brainard Canyon. There is no geologic evidence existing along the fault to suggest that the rate is greater.

PROBLEMS

The principal problem associated with mapping of upper Tertiary and younger sedimentary rock units displaced along the San Andreas fault from Palmdale southeast to Mile High is that their ages are poorly known or unknown. Mapping shows reasonably precise displacement relationships along the San Andreas involving perhaps 10 geologic units less than 2-3 Ma. To infer the ages of these units I have reconciled estimated age dates for deposits used in previous published reports with relative age factors that I have observed (weathering, depositional relationships, lithification, and deformation).

The extreme coarseness of Shoemaker Gravel and the very coarse gravel of Big Rock Creek implies that these units were deposited during an extremely wet time period. Subrounded boulders of gneiss and massive to foliated plutonic rocks to 4 m in maximum dimension exist in the Big Rock Creek gravels 5 to 10 km southeast of the mouth of Big Rock Creek canyon, 10-15 km from their source. I do not believe that the San Gabriel Mountains grew dramatically during this time, adding that factor to the extreme coarseness of the sediments. Extreme growth of the eastern mountains occurred after deposition of Shoemaker Gravel/Big Rock Creek gravels.

Good exposures of Pleistocene gravel units for possible dating exist in cuts along Big Pines Highway from Shoemaker Canyon to Mile High. These include cuts north of Caldwell Lake within the offset Pinyon Ridge fan.

PLANS

First I plan to complete a geologic map of the area along the San Andreas Fault from Big Rock Creek southeast to Jackson Lake and north to the north end of Mescal Creek canyon (Figure 12). Geologic relationships within this area reconcile the differences in sedimentary terranes to the northwest and southeast. For example, the area includes both the Juniper Hills Formation and Shoemaker Gravel (northwestern units) and the Crowder Formation and Mescal Creek beds (southeastern units). (Deposits I call "Mescal Ceek beds" previously have been mapped as Harold Formation.)

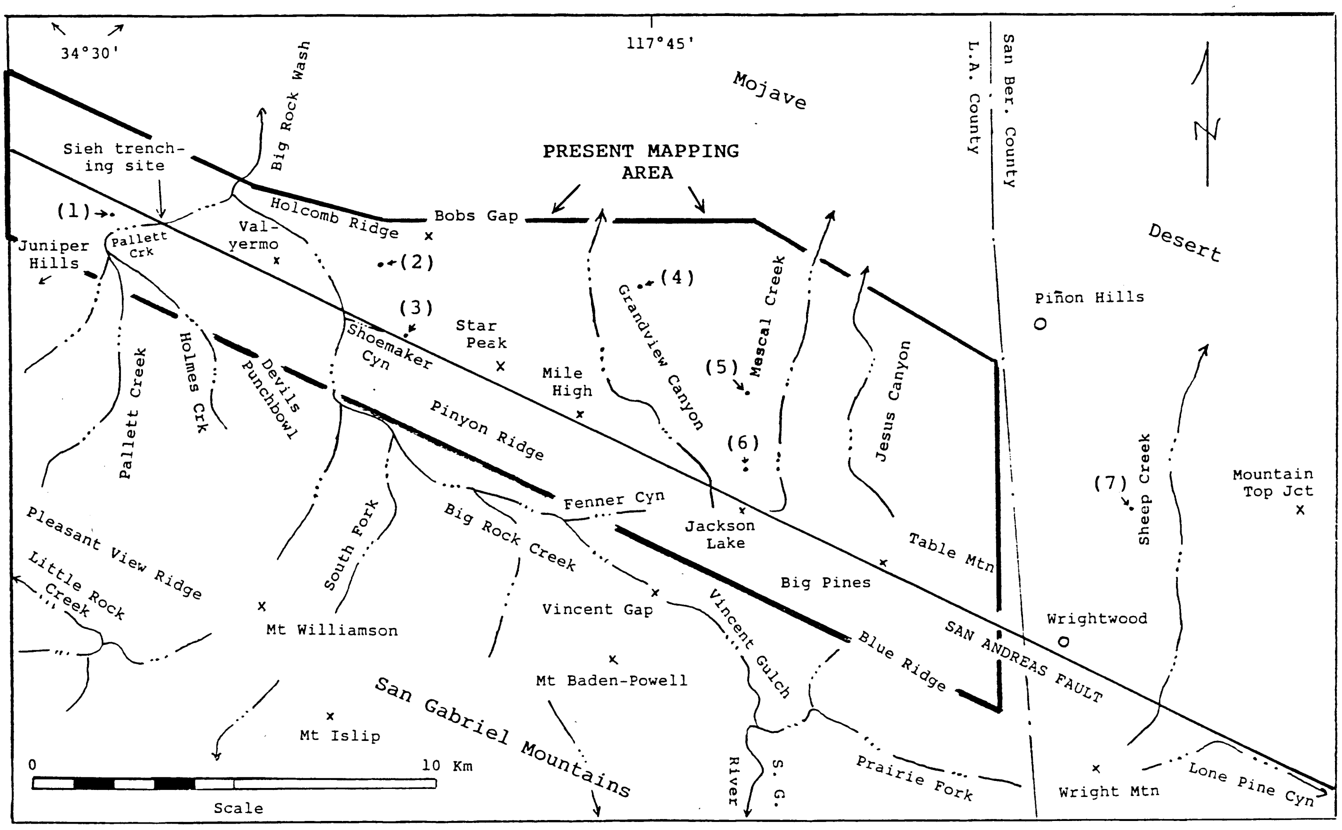

FIGURE 12. Map showing area where geologic mapping is in progress emphasizing depiction of Pleistocene sedimentary deposits. Localities are described on the following page and noted in the text.

FIGURE 12

(DESCRIPTIONS OF LOCALITIES)

(1). Coarse, mostly horizontal gravels exposed in south-facing cuts along Pallett Creek Road within 0.5 km east of Long-view Road appear to be Shoemaker Gravel (Juniper Hills 7.5-minute quadrangle).

(2). Shoemaker Gravel is exposed in artificial cuts bordering a small, abandoned dam about 0.5 km northeast of Mountain Brook Ranch (Valyermo quad). Paleocurrent structures in the deposits here indicate that they were deposited in a generally northeast direction.

(3). Shoemaker Gravel is exposed in cuts for Big Pines Highway on the north slope of Shoemaker Canyon (Valyermo quad). In the lowest cuts, at the north edge of the San Andreas fault zone, the deposits dip moderately to steeply north. From here to the top of the slope they are nearly horizontal; paleocurrent structures indicate they were deposited southeastward. In a lengthy south-facing cut at the top of the slope the deposits dip gently (±5°) west, reflecting their regional uplift to the east and southeast.

(4). In natural and artificial exposures 1 km west and west-northwest of Hagenbaugh Ranch, north-dipping rocks, from south to north, include Crowder Formation, Mescal Creek beds (wrongly identified as Harold Formation in previous studies), Shoemaker Gravel, and very coarse gravels apparently derived from Big Rock Creek canyon (Valyermo and Mescal Creek quadrangles).

(5). Very coarse gravels exposed in natural cuts at the east end of Big John Flat (uppermost slopes of Mescal Creek canyon) have a clast composition combining Shoemaker Gravel and very coarse gravel derived from Big Rock Creek canyon (Mescal Creek quad). They appear to have been deposited in a southeasterly direction.

(6). Gravels at Ball Flat (Mescal Creek quad), 1 km north of Jackson Lake, are similar to those at locality 5. Elevation of base of gravels at Ball Flat is 6,250 ft, 2,450 ft higher than gravels exposed at localities 1 and 2 (about 3,800 ft in elevation).

(7). Crowder Formation here, as exposed in road cuts (center W edge NE¼ SW¼ sec. 33, T4N, R7W, SBM; Phelan quadrangle), and to the east contains clasts of marble. Rocks to the west do not contain marble.

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